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Practical Paper

Analysis of pollution status of Amadi Creek and its management

J. C. Agunwamba, C. N. Maduka and A. M. Ofosaren

ABSTRACT

In this research work, the oxygen sag curve and purification capacity of Amadi Creek was studied. The reaeration constant (k_2) was computed from data generated by sampling the DO concentration along the creek from the point of waste discharge downstream while the deoxygenation constant (k_1) was determined by monitoring the BOD of samples obtained along the creek. The reaeration coefficient ranged from 0.09 d^{-1} to 0.17 d^{-1}. The Streeter–Phelps formula grossly under-estimated k_2. Hence, a new empirical model was derived by multiple regression analysis and was successfully verified with an independent set of data. The study not only identified and quantified the amount of effluent into the creek from various sources but also evaluated its assimilatory capacity which is important information for the prevention of further degradation of the creek water. The critical dissolved oxygen deficit was 3.6 mg/l while the existing dissolved oxygen was also 3.6 mg/l which falls below the 5.0 mg/l stipulated for fish life. The high level of pollution in the creek calls for some critical implementation of the recommended strategies.

Key words | Amadi Creek, management, reaeration coefficient, water pollution

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INTRODUCTION

Rivers and streams are one of the major receptacles of waste waters. Sometimes wastes are discharged into them arbitrarily without predetermining the impact of such discharges on aquatic life. The discharge of organic impurities, such as municipal sewage and industrial waste, into a body of water presents an important problem in the field of sanitary engineering. The decomposition of this organic material by bacteria results in the utilization of dissolved oxygen. The replacement of the oxygen by reaeration occurs through the water surfaces exposed to the atmosphere. Much research have been done on the mechanism of reaeration, factors affecting reaeration such as temperature, river geometry and hydrodynamic factors (McBride 1982; Agunwamba 2001*a,b*), assessment of assimilatory capacity of streams; and models of reaeration (Dobbins 1964; Cohen & O'Connell 1976; Campolo *et al.*, 2002). But that research was carried out in the developed countries with virtually no information available in the literature for the Nigerian environment.

Local research on this topic is very important since the reaeration coefficient is influenced by several environmental factors which are subject to both temporal and spatial variations. Such a study should be conducted in Amadi Creek, Port Harcourt. It is an important resource which sustains fishing activities and also provides a receptacle for industrial effluents. Although the self-purification processes which occur in a stream enable it to safely handle some wastewater discharges, there is a limit to its assimilatory capacity. An increase in the concentration of organic material

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stimulates the growth of bacterial, and oxidation proceeds at an accelerated rate. The concentration of waste can be so great that the receiving water body is completely devoid of oxygen.

Not recognizing that the creek has a limited capacity, some companies and communities discharge wastewaters haphazardly into streams and creeks, thereby jeopardizing the health of aquatic living organisms. There is a dire need for the proper assessment of streams in Nigeria to ensure control of waste discharges within a stream's assimilatory capacity which will subsequently result in improved water quality and optimum utilization (Roberts 1995). Hence, the objectives of this study include determination of the reaeration and deoxygenation constants for the creek under certain varying conditions; evaluation of the self-purification capacity of the stream; and determination of the allowable BOD loading.

Study area

The Amadi Creek is one of the many creeks that constitute the hydrological system in the Port Harcourt metropolis. Its length is approximately 20 km from Rumuodara community along the East–West road. It passes beside the Airforce Base, cuts across the new and old Aba Road, passing through Rumuobiakani, Oginigba, Trans Amadi and Woji communities. From Woji, it runs through Slaughter, Okujiagu and some Okirika communities, and finally empties into the old Calabar River. It receives much industrial effluents, runoff and sewage. Although it is not used as a drinking water source, it sustains much fishing activities. The location of Amadi Creek and its environs are shown in Figure 1.

Due to limited time and the huge financial implications, readings were taken at high tide. For a more comprehensive analysis, sampling should cover both the rainy and the dry seasons and at both high and low tide.

METHODOLOGY

Data acquisition

Samples were collected over a period of three months between July and October 2002 from aboard a boat along a distance of about 2,800 m along the creek at 200 m interval. Two samples of the creek water were obtained from each of the fifteen stations for determination of DO and BOD in the laboratory. Other parameters determined include creek depth, width, water temperature and flow velocity. The DO for successive stations were determined, starting from 9.20am on Monday 11 July. From the data obtained, the reaeration constant (k_2) was determined. The BOD values for selected stations were determined each day for a period of seven days. In addition, several visits were made to the communities and settlements along the banks of the creek to determine the BOD of sewage contributions to the creek (see Figure 2).

Determination of the reaeration constant (k_2)

The parameter k_2 was obtained from experimental results using

$$k_2 = \frac{\log D_o - \log D}{t} \tag{1}$$

where D_o is the initial deficit at the upstream, D is the deficit at any downstream point and t is the travel time between two points.

Calibration and verification of k_2 model

A model for k_2 of the form

$$k_2 = \frac{a_1 U^{b1} C_{e1}}{R^{d_1}} \tag{2}$$

was formulated using multiple regression based ion measured data. The parameters U, C and R denote the stream velocity, Arrehius constant and stream hydraulic radius respectively. The model was later verified with an independent set of data and then compared with the predictions from the Streeter–Phelps model (Agunwamba 2001*a,b*):

$$k_2 = \frac{5.026 U^{0.969} (1.024)^{T-20}}{R^{1.673}}. \tag{3}$$

The BOD and DO were determined following the procedures given in the *Standard Methods* (APHA/AWWA/WEF 1992). There was no existing accurate population figures for the communities and settlements. Hence, the population figures were estimated by determining the number of occupants in a few settlements and multiplying the average by the number of settlements. The BOD contributed per

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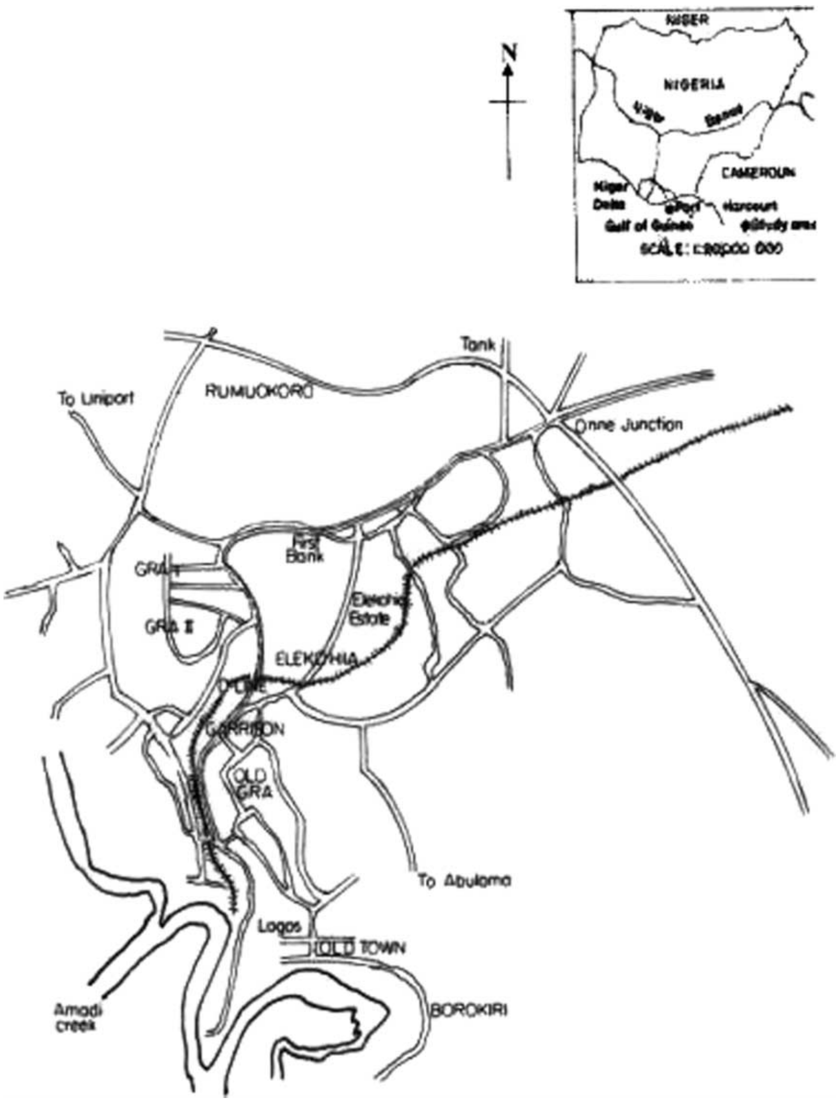

Figure 1 | Port Harcourt metropolis road network map showing Amadi Creek. Source: River State Lands and Housing Bureau.

person per day in most developing countries is taken as 0.045 kg (Oluwande 1978).

A map of Port Harcourt metropolis was obtained from the Rivers State Land and Housing Bureau. Samples were collected every 200 m downstream using standard DO samplers. After taking the necessary precautions to prevent deterioration, the samples were returned to the laboratory and analyzed according to the procedures specified in the *Standard Methods* (APHA/AWWA/WEF 1992). The depths were measured by dropping a loaded tape to the bottom of the creek. The width of the creek was measured by stretching a tape across the creek. Temperature readings were taken with a thermometer at every station simultaneously with the other readings. Time was measured with an electronic clock while the flow velocity was determined with a current meter.

Determination of the deoxygenation constant k_1 for Amadi Creek

The deoxygenation constant k_2 was determined using the Thomas method:

$$\frac{t^{1/3}}{x} = (K_1 L)^{-1/3} + \frac{K_1^{2/3} t}{6L^{1/3}} \tag{4}$$

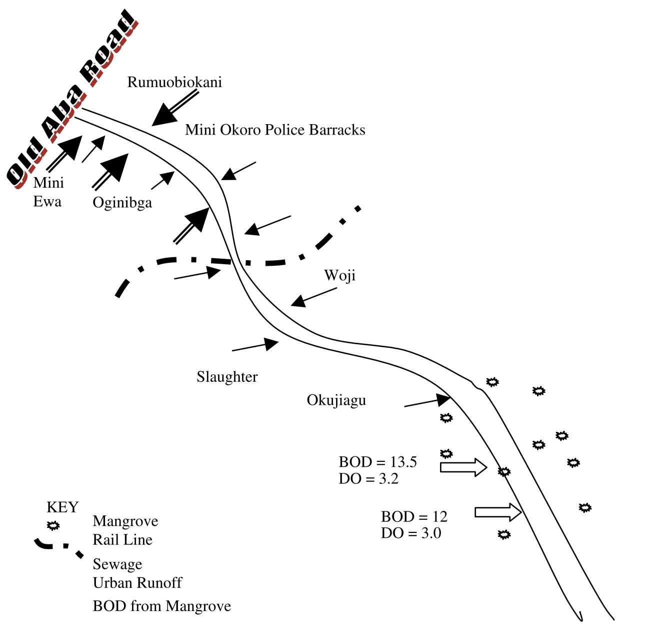

Figure 2 | A sketch of Amadi Creek showing the BOD, DO and Q of effluent discharged into it.

where $t = \text{time}$, $k_1 = \text{deoxygenation constant}$, L is the organic matter oxidized and x is the organic matter remaining.

Oxygen sag

The oxygen sag was predicted using (James 1993)

$$D_t = \frac{k_1 L_o}{k_2 - k_1}(e^{-k_1 t} e^{-k_2 t}) + D_o e^{-k_2 t} \tag{5}$$

where D_o is the initial dissolved oxygen deficit and L_o is the ultimate BOD_5. The D_o, BOD and temperature of the mixture of effluent with creek water is obtained from

$$x_m = \frac{x_e Q_e + x_S Q_S}{Q_e + Q_S} \tag{6}$$

where x_m represents any parameter such as D_o, BOD_5 and water temperature at the point effluent mixes with creek water; the subscript S denotes stream (or creek); e stands for effluent; and Q_s and Q_e are the creek and effluent discharges respectively. The various wastewater input parameters into Amadi Creek were obtained using Equations (5) and (6).

RESULTS AND DISCUSSIONS

The results on the variation of k_2 with the geometric parameters, effect of temperature and verification of the k_2 model are shown in Figures 3–8, respectively.

Variation of k_2 with the geometric parameters

Figures 3 and 4 show the variation of ln k_2 with log of hydraulic radius (ln R) and log of velocity and ln U, ln R with ln U. The coefficients of regression between ln k_2 and ln R is -0.8837; ln k_2 and ln U, 0.9418; and ln U and ln R, -0.8677. The high coefficient of correlation between ln k_2 and ln U is expected since the higher the velocity the higher the rate at which air is absorbed from the atmosphere. There is a negative correlation between k_2 and hydraulic radius. Generally, R increases with depth; hence, the negative correlation between k_2 and R.

Effect of temperature

The effect of temperature on DO is shown in Figure 6 for the data generated at the five stations. As temperature increases DO concentration reduces. The effect of temperature on k_2 is shown in Figure 7. The coefficient of correlation between k_2 and temperature for the stations vary from 0.5000 to 0.8885. The fifth station (which was not plotted) gave a very low correlation, probably because of an error in measurement.

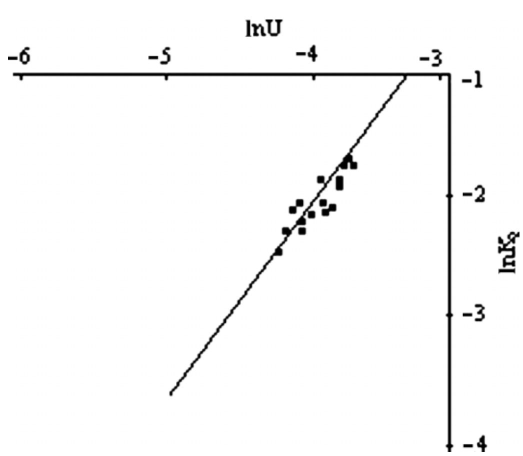

Figure 3 | Variation of ln k_2 with ln U.

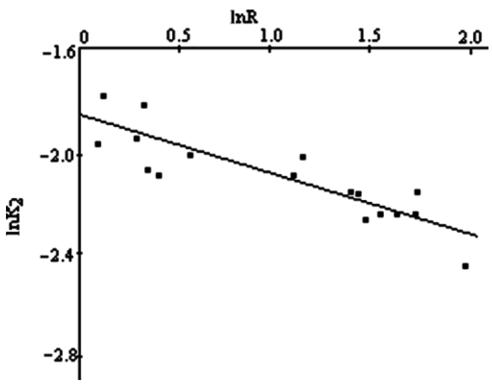

Figure 4 | Variation of ln k_2 with ln R.

Prediction of k_2

Equation (3) did not give good predictions of k_2. The coefficient of correlation between the predicted and the measured was -0.0517 while the slopes and intercepts were -0.1132 and 0.0506, respectively. The predicted values were far lower than the experimentally determined values. The result of multiple regression analysis generated an equation of the form

$$k_2 = \frac{11.6325U^{1.0954}}{R^{0.0016}}. \quad (7)$$

The values of the reaeration coefficient predicted by the new model are in good agreement with the observed values (Figure 8). The coefficient of correlation is 0.6965 with a slope and an intercept of 0.4295 and 0.0839, respectively.

Oxygen sag curves

The reaeration coefficient (k_2) varies from a maximum value of 0.17 d^{-1} to a lowest value of 0.09 d^{-1} with an average value of 0.127 d^{-1}. The deoxygenation constant (k_1) was

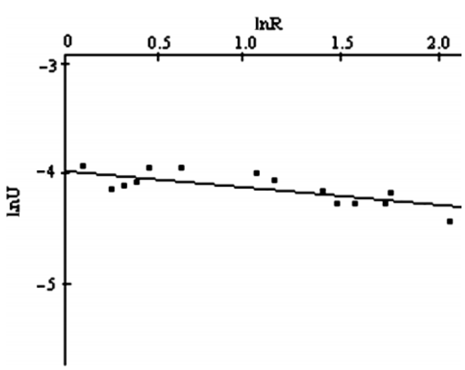

Figure 5 | Variation of ln U with ln R.

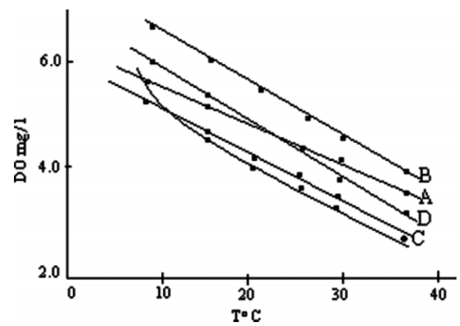

Figure 6 | Effect of temperature on DO for the different stations (A, B, C, D and E).

determined as 0.042 d^{-1}. Hence, the purification factor, $f = k_2/k_1 = 3$.

The measured dissolved oxygen saturation concentration was found to be 7.2 mg/l at 28°C. The critical dissolved oxygen, 3.6 mg/l, occurred at 1,400 m (x_c), giving a deficit of 3.6 mg/l.

The critical time (t_c) is therefore 1,400/0.0152 s ≅ 1.07 d. The oxygen sag along the study reach was computed using Equation (5) based on the parameters given in Table 1. The measured and computed oxygen sag curves are shown in Figure 9.

The predicted DO deficit (DO_{cprd}) is 3. 2 mg/l at 1,600 m, giving a critical deficit of 4.0 mg/l. The critical time (t_c) is 1.22 d. The disparity between the measured and predicted oxygen sag curves is attributable to the omission of some factors which are known to affect the oxygen sag from Equation (5). The measured oxygen sag curve, on the other hand, captures the effects of the entire processes going on simultaneously in the stream such as removal of BOD by sedimentation and adsorption, addition of BOD along the stretch and from bottom deposits and the addition of oxygen due to photosynthesis and respiration of aquatic plants.

IMPLICATION OF FINDINGS

It was revealed that, apart from being a channel of waste disposal, the Amadi Creek also provides water for fishing. The communities depend on other sources for domestic and industrial supply that must meet higher criteria relative to that required for fishing. A common minimum DO requirement for fishing life is 5.0 mg/l. Since the DO saturation concentration for unpolluted fresh water at 28°C is 7.2 mg/l, the maximum allowable critical deficit D_c for Amadi Creek should be 2.2 mg/l.

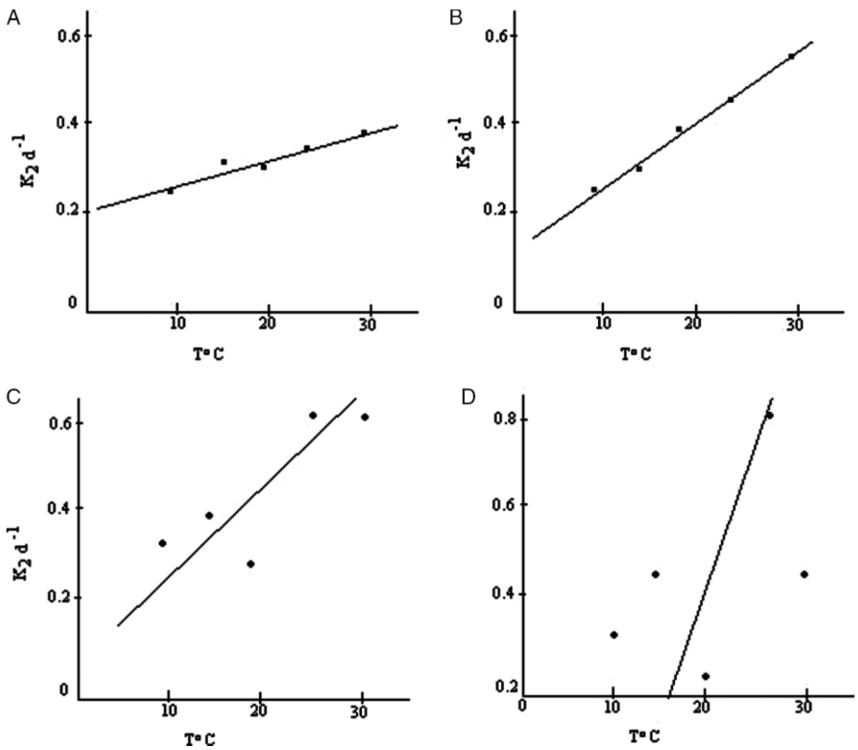

Figure 7 | Effect of temperature on k_2 at the various stations A, B, C and D.

Allowable BOD loading of Amadi Creek

The allowable BOD loading is obtained from

$$L_o = D_e e^{k_1 t_c} f \tag{8}$$

where L_o = allowable BOD load; D_c = allowable critical deficit; t_c = critical time; and f = self-purification ratio.

Since $D_c = 2.2$ mg/l, $t_c = 1.07$ d and $f = 3$, L_o is 7.0 mg/l.

Dilution requirement for Amadi Creek

The dilution requirement (Q) is given by

$$Q = 185.5\frac{L}{L_o} \tag{9}$$

where L is the first stage BOD expressed in lb per capita per day, Q is the required stream flow (cubic feet per second) and L_a is the permissible loading (mg/l). The factor 1,885.5 accounts for conversion of units of L/Q into mg/l (Fair *et al.* 1971).

For Amadi Creek, L_o = allowable BOD load = 7.0 mg/l; L = BOD of effluent (max) = 1,000 mg/l. Therefore Q = river flow rate l/d = 26,500 l/d.

WATER QUALITY MANAGEMENT FOR AMADI CREEK

Knowledge of all the sources of pollution of Amadi Creek is essential for determination of the effective water quality management strategy (Hadrian 1998).

Sewage is a major source of pollution of Amadi Creek. The sewage comprises of urine and faeces from the pier latrines of Rumuobiakani, Mini Ewa, and Oginigba

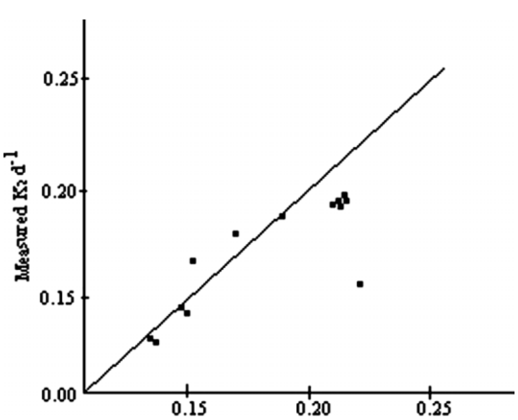

Figure 8 | Verification of the new predictive equation.

Table 1 | Predicted stream characteristics for Amadi Creek

			Effluent parameters			Stream parameters			Mixture parameters		
Discharge position	Discharge position (m)	Effluent type	D_e (mg/l)	L_e (mg/l)	Q_e (m^3/s)	D_s (mg/l)	L_s (mg/l)	Q_s (m^3/s)	D_a (mg/l)	La (mg/l)	Q_a (m^3/s)
Rumuobiakani	0	Pie latrine sewage	2.5	1,000	1.818×10^{-5}	4.1	7.59	0.139	4.10	7.72	0.139
Mini Ewa	150	Domestic sewer	3.0	500	3.5×10^{-5}	4.0	7.68	0.56	3.99	7.71	0.56
Mini Ewa	400	Pie latrine sewage	2.8	1,000	1.818×10^{-5}	3.83	7.65	0.635	3.83	7.69	0.635
Oginigba	600	Urban run off	3.5	20	0.5	3.70	7.64	1.296	3.64	11.10	1.796
Oginigba	900	Domestic sewage	2.8	500	4.6×10^{-4}	3.64	11.10	1.796	3.64	11.22	1.797
Woji	1,200	Drainage	3.4	25	0.65	3.43	11.11	10.213	3.43	11.94	10.863
Trans Amadi Industrial Area	13,500	Urban run off	3.8	15	1.02	3.31	11.88	14.850	3.34	12.09	15.870
Slaughter	1,600	Urban run off	3.9	150	0.08	3.17	11.99	2.457	3.20	16.35	2.537
Okujiaku	2,000	Run off from drainage	4.0	13.5	8.5	3.00	16.13	8.904	3.49	14.85	17.4
Okujiaku	2,400	Run off from drainage	4.5	11.5	10.8	3.20	14.66	26.096	3.59	13.73	36.896
Mangrove	2,800	Run off from mangrove	5.0	10.2	15.5	3.28	13.55	63.00	3.62	12.93	78.50

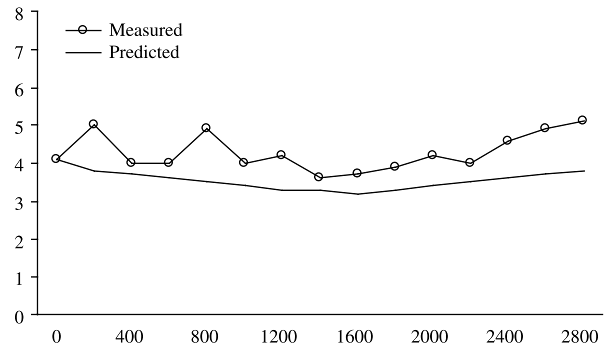

Figure 9 | Predicted and measured oxygen sag curve for Amadi Creek.

communities. It also comprises of sullage, domestic and industrial wastewater and waste from sewerage piped straight into the creek. The BOD of the sewage ranges between 500–1,000 mg/l, while its flow rate is between 1.8×10^{-5}–4.6×10^{-4} m^3/s.

Urban runoff is another source of pollution of Amadi Creek. The runoff from the densely populated Mini Ewa and Oginigba, highly industrialized Trans Amadi, and Woji with poor sanitary condition and high rates of waste generation contribute runoff with BOD_5 in the range of 20–100 mg/l and flow rate of up to 0.5 m^3/s.

Industrial activity and discharges from the Trans Amadi industrial area are associated with different types of chemical pollutants, organic and inorganic matter, toxic chemicals and microbial organisms. Even though the industrial discharges have little impact on the oxygen resources of the creek due to its low BOD, its influence on the water quality of Amadi Creek cannot be overlooked.

Solid waste containing industrial solid, paper, cans, construction waste, food waste and residues from burning find their way into Amadi Creek. These solid wastes significantly exert a significant amount of BOD on the creek, especially solid wastes of organic origin such as food waste.

The Rivers State Government is considering the proposal for improved prevention of pollution and sewage disposal around the creek. The proposal includes selection, design and construction of appropriate sewage disposal systems, and implementation of a holistic management strategy for control of pollution in the creeks. The strategy will involve public enlightenment on hygiene and sanitation, community participation maintenance and catchment management. Catchment management will involve traversing the whole stretch of the creek, identifying each point source pollution location, quantifying its contribution to the pollution of the creek and adopting appropriate mitigation measures.

An appropriate sewage system is very crucial not only for safe treatment and disposal but also for improving environmental health and aesthetics. In addition, it is envisaged that the construction of appropriate sewage facilities will indirectly boost the tourist trade and other economic activities in the area.

In addition to this, all the drains which feed into Amadi Creek should be fitted with grit to screen off solids which may have found their way into the municipal drainage system. The already existing dump sites, transit sites and transfer stations such as the ones at Mini okoro bridge, Mini Ewa, Woji, Slaughter and Rumuodara should be evacuated and reclaimed.

Also, the self-purification of Amadi Creek can be improved by dredging. Dredging will increase the velocity of stream flow and in turn increase the rate of rearation by atmospheric absorption, reduce the addition of BOD from bottom deposits, and eliminate weeds.

CONCLUSION

The analysis of Amadi Creek has shown that the creek is seriously polluted. It receives BOD load in excess of 700 mg/l, which far exceeds the allowable BOD loading of 7.0 mg/l. The reaeration coefficient varied from 0.09 d^{-1} to 0.17 d^{-1}. As is expected, the Streeter and Phelps model which was derived outside the Nigerian environment does not give an accurate result for reaeration. Hence, another equation which may be used for prediction in creek waters under similar environmental conditions was presented and verified with good results. This study also reveals that the communities around Amadi Creek depend on it for fishing. The minimum dissolved oxygen requirement for fish life is 5.0 mg/l, but analysis revealed an existing DO of 3.6 mg/l. This implies a critical deficit of as high as 3.6 mg/l as against the 2.2 mg/l allowable critical deficit prescribed for such a stream. For an allowable BOD loading of 7.0 mg/l, the dilution requirement prescribes that for an effluent of BOD, L, the minimum discharge of the receiving stream should be

26.5 m^3/d for the self-purification capacity not to be exceeded. It was observed that in several stretches of the creek this requirement was not met. For instance, around the Slaughter area where the discharge is 2.5 m^3/s, the effluent from animal waste was about 1,000 mg/l. The flow required for effective elimination of the waste is 26,500 l/d. Both preventive and control strategies should be adopted for effective conservation of Amadi Creek resources.

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